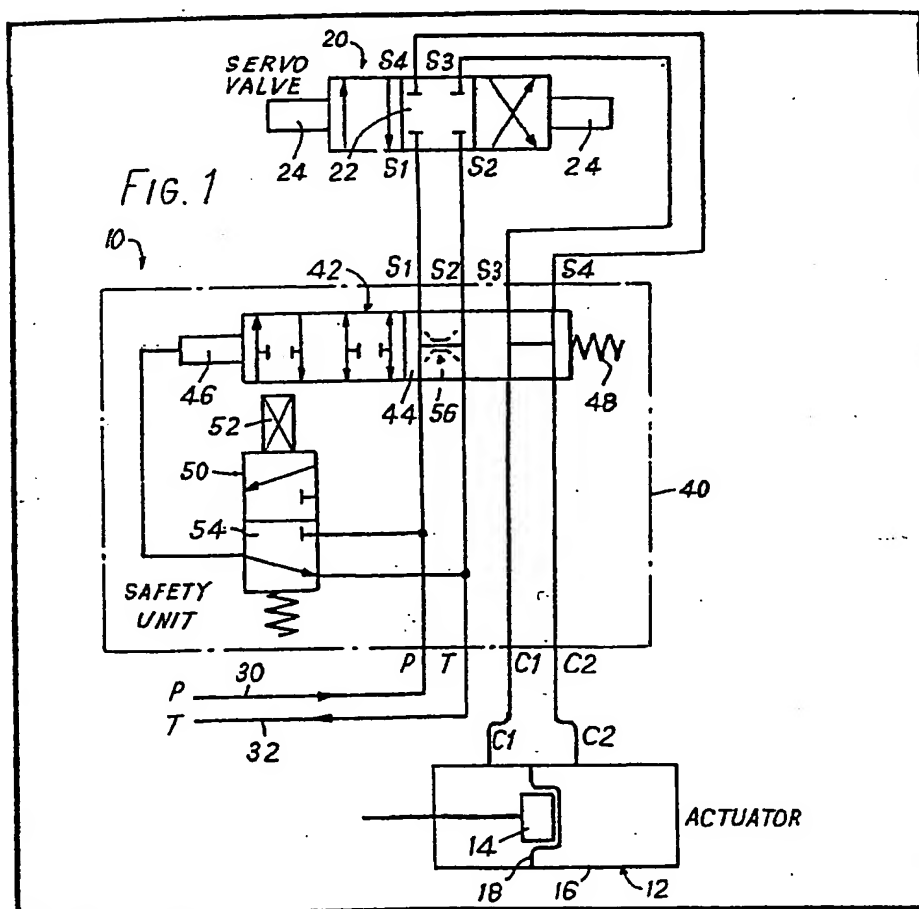


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(54) Hydraulic Control Apparatus

(57) A hydraulic control system (10) connects pump and tank input lines (30,32) to output lines (C1,C2) which are connected to an actuator (12) which incorporates a rolling diaphragm (18). An electrically controlled servo valve (20) selectively connects the input and output lines. A safety unit (40) is incorporated into the system so that in the event of failure of either the hydraulic pressure

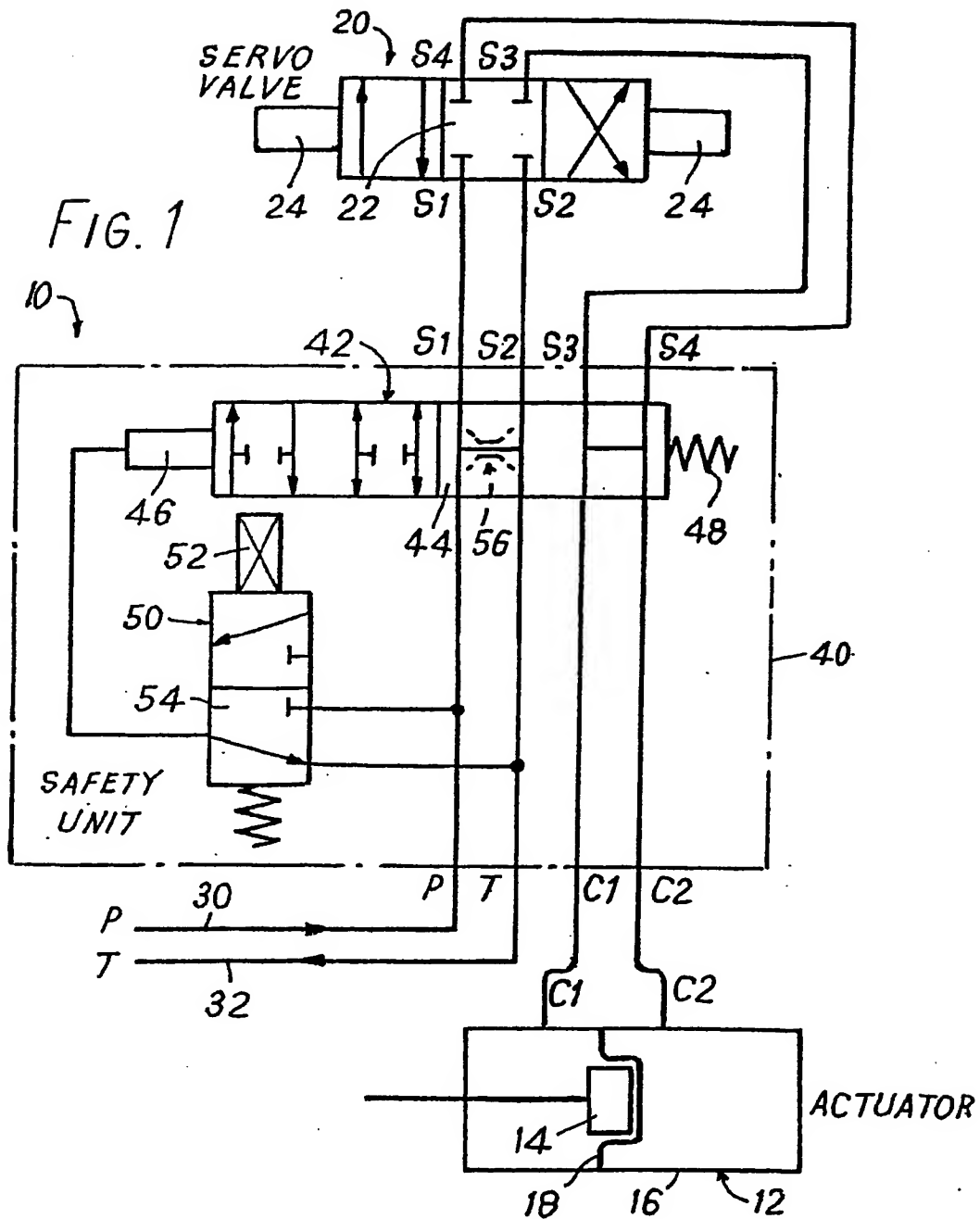
or the electrical supply, the output ports (C1, C2) are coupled together to avoid damage to the actuator. To this end a solenoid valve (50) when energised connects the pump to one end of a spool valve (42) to move it against the force of a spring (48). If either the solenoid is de-energised or the hydraulic pressure falls, then the spring (48) returns the spool (44) to a position where the output ports (C1, C2) are connected together and also the input ports (P, T) are connected together.

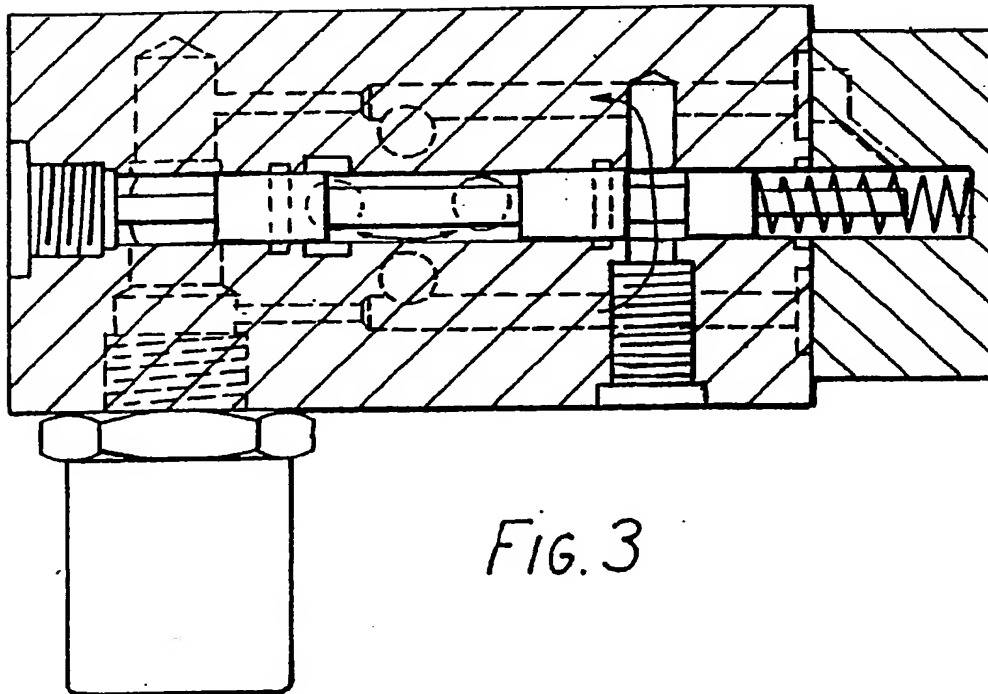
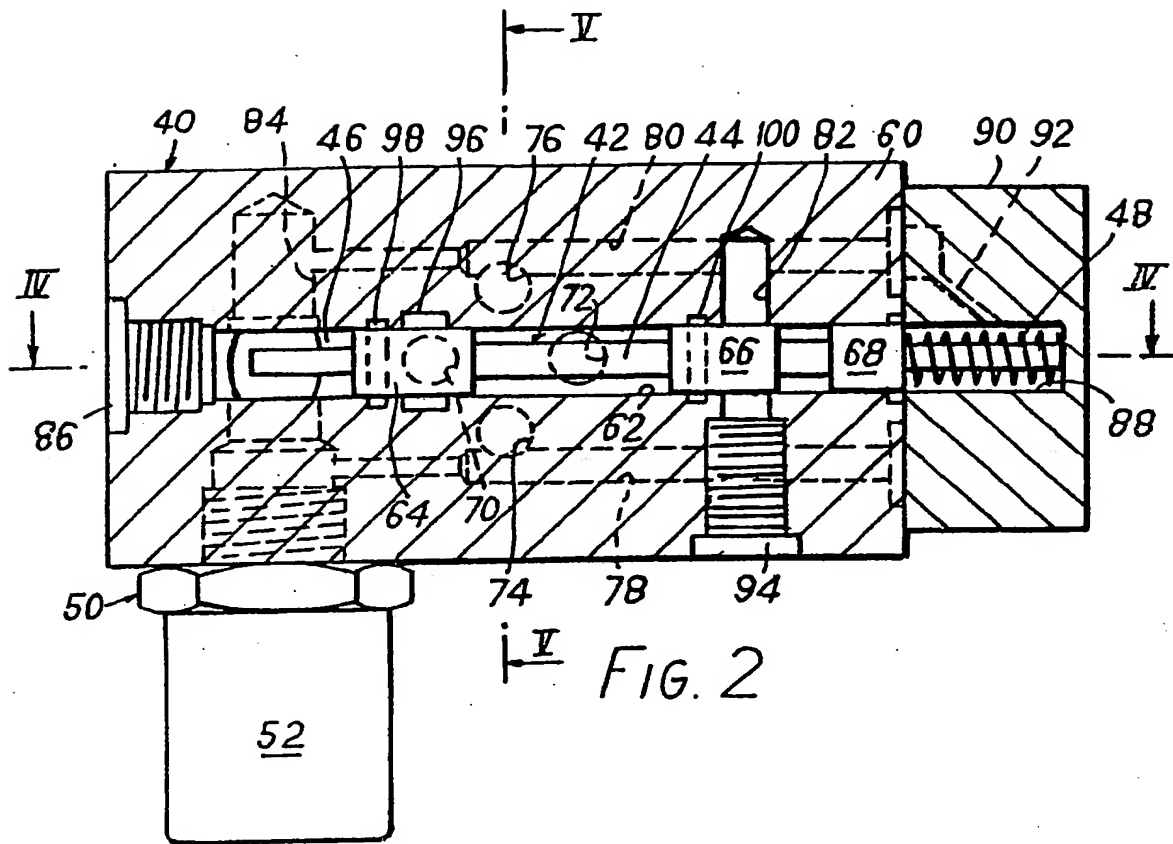


Figs. 6 & 7 of the drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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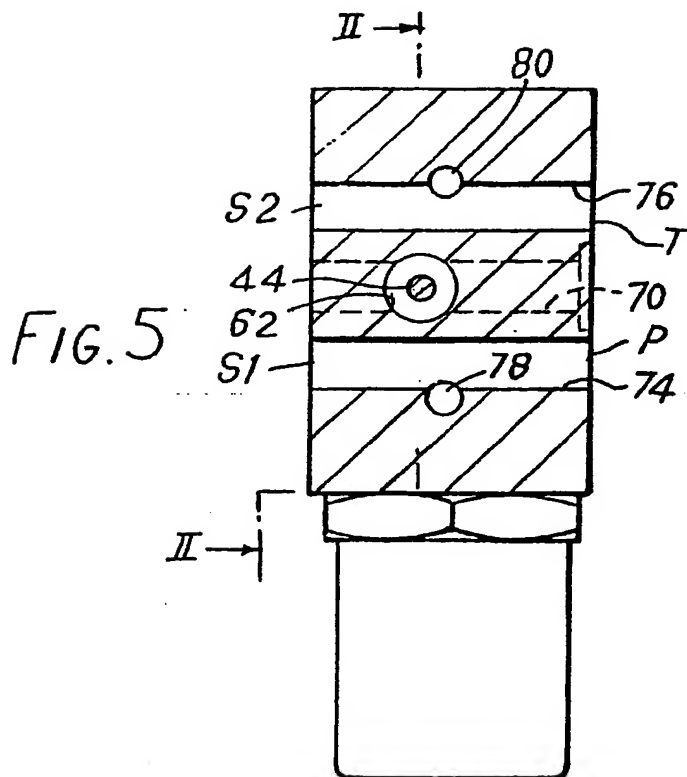
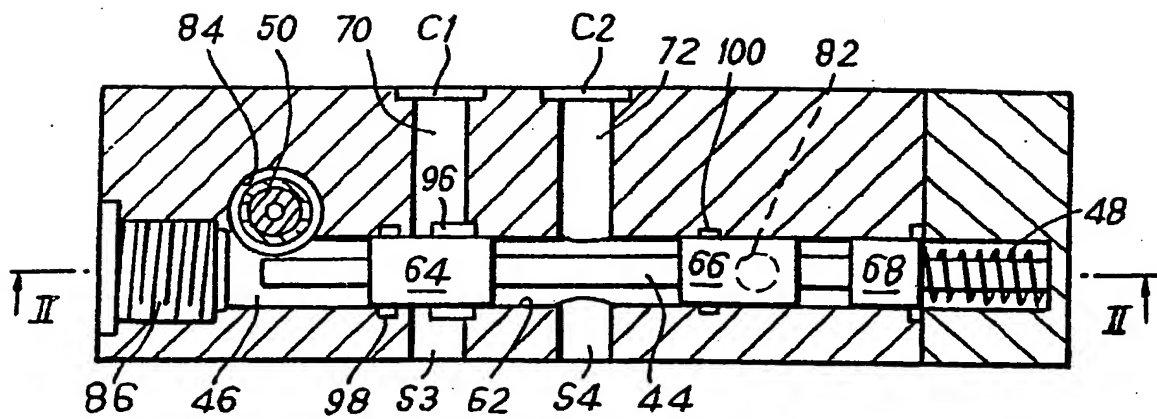
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FIG. 4



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FIG. 7

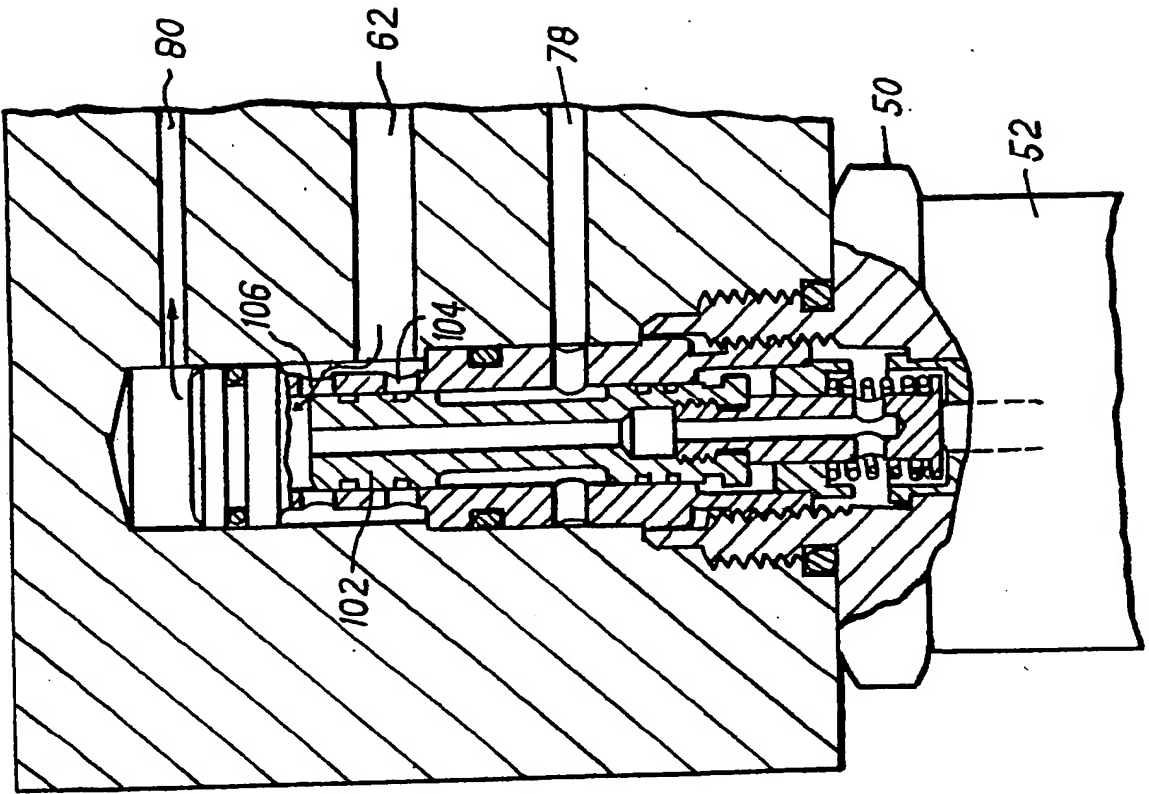
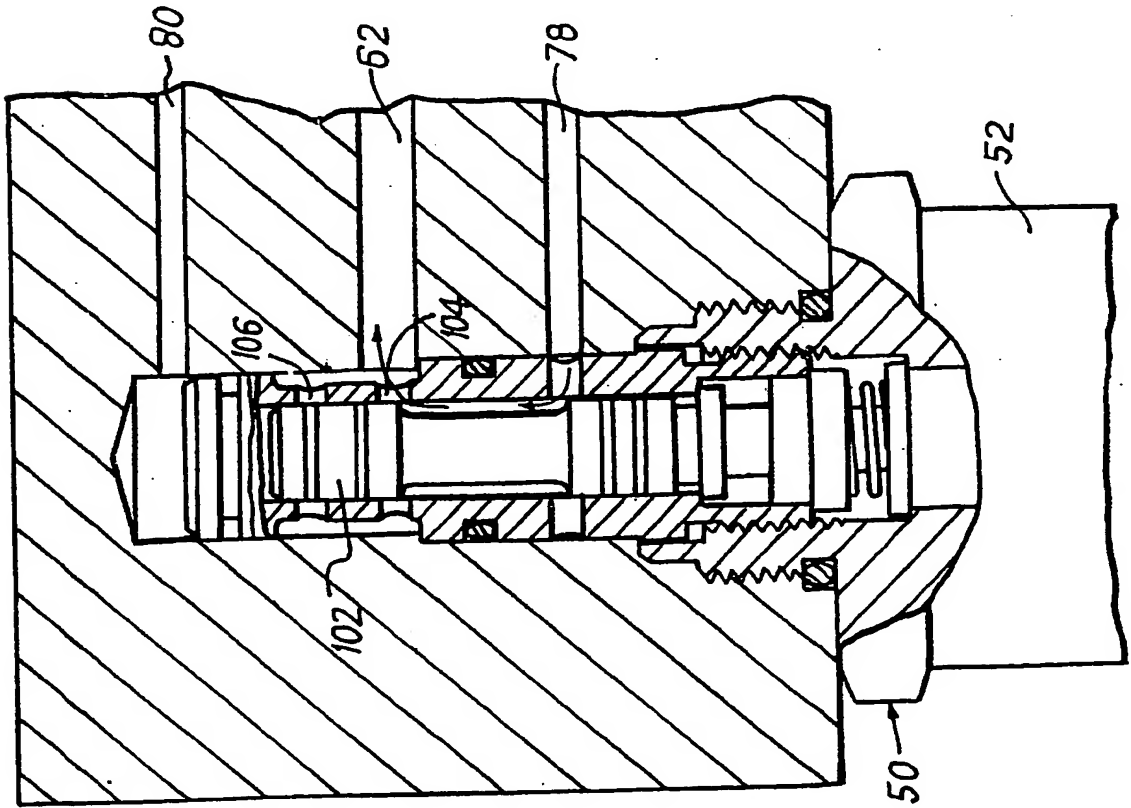


FIG. 6



# SPECIFICATION Hydraulic Control Apparatus

This invention relates to hydraulic control apparatus.

- 5 A piston-and-cylinder hydraulic actuator is proposed in our British Patent Application No. 79,22765 which utilises rolling diaphragms as seals. Diaphragms of this type are particularly prone to damage if negative pressures are induced in the cylinder, such as could occur if the hydraulic pressure supply fails. To minimise this possibility it has been proposed to incorporate a series of discrete check valves and manifolds into the system, so as to achieve a situation in which the hydraulic fluid is trapped in the cylinder. A multiplicity of valves is necessary to ensure that no leakage occurs, and an increased number of joints means that the possibility of leakage is increased.

- 20 Similar problems may arise in other instances, for example where the control system is dependent upon an electrical supply and the electrical supply fails.

- 25 This invention is defined in the appended claims, to which reference should now be made.

The invention will be described in more detail, by way of example, with reference to the drawings, in which:—

- 30 Fig. 1 is a schematic function diagram of a hydraulic control system embodying the invention;

- Fig. 2 is a front elevational sectional view through a safety unit forming part of the system, with the solenoid valve shown in the energised condition and the spool valve actuated;

- 35 Fig. 3 is a similar view of the safety unit in the absence of hydraulic and/or electrical power;

- Fig. 4 is a sectional view taken on the line IV—IV in Fig. 2;

- 40 Fig. 5 is a sectional view taken on the line V—V in Fig. 2; and

- Figs. 6 and 7 show details of a solenoid valve, incorporated in the safety unit, and shown in its energised and de-energised conditions

- 45 respectively.

- Reference will first be made to Figure 1, which shows diagrammatically the main components of a hydraulic control system 10. An actuator 12, shown schematically, is of the type having a piston 14 and a cylinder 16, with two fluid supply ports C1 and C2, and in which the seal is formed by a rolling diaphragm 18. Such an actuator is described in our aforementioned application. A servo valve 20 is used to control the actuator. The servo valve 20 has a spool 22, shown in conventional form, having an actuating torque motor 24.

- The electrically-controlled torque motor 24 is connected to a flapper which is mounted between two nozzles; these nozzles are connected to chambers at either end of the spool 22. Energising the torque motor 24 will move the flapper in the appropriate direction, causing a pressure difference in the nozzles, and hence a

- 65 pressure difference across the spool. As the spool moves due to this pressure imbalance the flapper, which is mechanically connected to the spool, moves away from the high pressure nozzle until the spool is in equilibrium again. This movement of the spool, and hence the flow, is proportional to the applied electrical signal.

The servo valve 20 has four ports labelled S1, S2, S3 and S4, and the spool 22 has three possible positions as follows:—

- 70 (1) Central position—all four ports are closed, as shown.  
(2) First energised position—S1 and S4 are connected and S2 and S3 are connected.  
(3) Second energised position—S1 and S3 are connected and S2 and S4 are connected.

- 80 The hydraulic system is powered by a pressure differential between input lines 30 and 32 which are connected respectively to the pump (P) and the tank (T) of the hydraulic system. In a

- 85 conventional system the P and T lines would be connected to the ports S1 and S2 of the servo valve, and the ports S3 and S4 of the servo valve would be connected to the actuator ports C1 and C2. In this way, the actuator could be moved to

- 90 left or right by energisation of the torque motor 24 or would be left stationary if neither solenoid is energised.

- In the event of failure of the hydraulic or electrical supply, it is possible with such a system, for negative pressures to be induced in the actuator 12 by movement of the piston rod by external means. With a conventional piston and cylinder actuator this may not matter, but with a rolling-diaphragm actuator this can be detrimental. To overcome this problem a pilot-operated safety unit 40 is connected between the input lines 30 and 32, the servo valve 20, and the actuator 12, as shown in Fig. 1.

- The safety unit 40 consists in principle of two main components, namely a spool valve 42 and a solenoid valve 50. The spool valve 42 has a schematically-shown spool 44 provided with eight ports for connection respectively to the P and T lines, the ports S1 to S4 of the servo valve, and the actuator ports C1 and C2. The spool is operated by fluid pressure in a chamber 46. When the chamber 46 is connected to the pressure line P, the spool 44 is moved to the right, but when the pressure is removed the spool is moved to the left by the action of a spring 48.

- The connection of the chamber 46 to the pressure line P is controlled by the solenoid valve 50 having an electrical solenoid 52. The valve 50 is connected to the input lines 30 and 32 as well as the chamber 46. The spool 54 of valve 50 has two positions; when the solenoid 52 is energised the valve connects the pump line P to the chamber 46, while when it is de-energised the chamber 46 is exhausted to the tank T, this being the position shown in Fig. 1.

- 125 The solenoid 52 is connected to the electrical supply for the control system. Thus if either the hydraulic pressure ceases or the electrical supply fails, the chamber 46 will be de-pressurised,

allowing spring 48 to move the spool 44 of valve 42 to the position shown.

The spool valve 42 operates so that:—

- 5 (1) In the left-hand position of The spool 44 as shown, i.e. with the spool moved to the right:
  - line P is connected to port S1
  - line T is connected to port S2
  - port S3 is connected to port C1 and
  - port S4 is connected to port C2.
- 10 (2) In the right-hand position of the spool 44, i.e. with the spool moved to the left:
  - lines P and T and ports S1 and S2 are all connected together, and
  - ports S3, S4, C1 and C2 are all connected
  - 15 together.

- It will be seen that in the first of these two conditions the safety unit 40 has no effect on the system and places it in precisely the same state as the known system described above. In this
- 20 condition the servo valve 20 can be operated selectively to couple each of the actuator ports C1 and C2 to a different one of the input ports P and T, depending on the energisation of the torque motor. When in the second condition, however,
  - 25 the safety unit connects the two actuator ports C1 and C2 to each other. This equalises the pressures in the actuator chambers and removes the pressure differential across the diaphragm 18. Any external disturbance to the actuator piston
  - 30 rod will now permit fluid to flow from one side of the actuator to the other, thus avoiding negative pressures on the diaphragm. In this condition of the spool valve 42, furthermore, the pump and tank lines will be connected together, as will the
  - 35 associated ports S1 and S2 of the servo valve 20 which are connected to them.

If the hydraulic pressure fails alone, the servo valve will remain in the 'control shut off' position.

- 40 The solenoid 52 of the solenoid valve will conveniently be connected to the electrical supply for the torque motor, so that it cannot be energised unless power is available for the servo valve. Furthermore, a separate switch may be provided so that the operator can de-energise the
- 45 solenoid 52 irrespective of whether power is available.

- If electrical failure is not a problem and the safety unit is required to respond only to a failure in the hydraulic pressure, the solenoid 50 can be
- 50 omitted, and the chamber 46 connected instead directly to the fluid pressure line P.

- In the initial condition of the device, or following a failure resulting in de-energisation of spool 44, the pump and tank ports are coupled
- 55 together. Thus even when the pressure is again applied to chamber 46, there may be insufficient differential to move the spool 44 against the spring 48. To overcome this a mild restrictor could be included, for example at the position
  - 60 indicated by reference 56 on Fig. 1.

- The number of parts required in the safety unit 40 to ensure that the actuator ports C1 and C2 remain connected together with negligible leakage for long periods is small. The physical
- 65 construction of one example of the safety unit will

now be described with reference to the remaining figures of the drawings.

- Referring to Figs. 2 to 5, the safety unit 40 comprises a body 60 which has a longitudinal
- 70 bore 62 (left-to-right on Fig. 2) for receiving the spool 44 of the spool valve 42. The spool 44 has three lands 64, 66 and 68. Four bores are made through the block in the front-to-back direction. Two of these bores, namely bores 70 and 72,
  - 75 pass through the centre line of the spool bore 62. The two ends of bore 70 form ports C1 and S3, while the two ends of bore 72 form ports C2 and S4, as seen in Fig. 4. The other two of the front-to-back bores 74 and 76 do not intersect the bore
  - 80 62, but each intersects a respective longitudinal bore 78 or 80. The two ends of bore 74 form ports P and S1, while the two ends of bore 76 form ports T and S2, as seen in Fig. 5.

- The longitudinal bores 78 and 80 are cross-connected by two up-and-down bores 82 and 84. The bore 82 passes through the centre line of the spool bore 62 and intersects the bores 78 and 80. The other bore 84 lies slightly behind (as seen in
- 85 Fig. 2) the bores 78 and 80 but is sized to intersect the three longitudinal bores 62, 78 and 80, and also to receive the solenoid valve 50, the solenoid 52 of which extends below the block 60.

- When energised, the solenoid valve 50 permits fluid communication between its intersections
- 95 with bores 78 and 62 but between its intersections with bores 62 and 80, and *vice versa* when de-energised. The intersection with bore 62 corresponds to the chamber 46 in Fig. 1. The construction of the solenoid valve 50 is
  - 100 described in more detail below with reference to Figs. 6 and 7.

- The bores 70, 72, 74 and 76 are through bores each forming a port at each end. Bore 62 is a through bore plugged at the end forming the
- 105 chamber 46 by a plug 86 and opening at the other end into a bore 88 in a separate block 90. This bore 88 receives the spring 48 which biases spool 44, and is in communication with the bore 80 by means of a bore 92 in block 90 to vent any leakage past land 68. Bores 78, 80, 82 and 84
  - 110 are blind bores, of which bore 78 is closed by the block 90 and bore 82 is plugged by a plug 94, which incorporates the restrictor 56 if this is present.

- The lands 64, 66 and 68 are located on the spool 44 as follows. It should be noted that the spool 44 has two positions as shown in Figs. 2 and 3 respectively; in Fig. 2 the spool is
- 115 "energised" against the spring and in Fig. 3 it is de-energised. No reference numerals are given on Fig. 3 to allow the parts to be seen more clearly. Land 64 is positioned to that when the spool is energised it blocks bore 70 from bore 62, but nevertheless fluid can flow along the length of
  - 120 bore 70 between bores C1 and S3 because the bore 70 is enlarged at its intersection with bore 62 as shown at 96. When the spool is de-energised, land 64 moves to permit communication along bore 62 between bores 70
  - 125 and 72. An O ring seal 98 positively seals the land
  - 130

64 in the bore 62 so as to inhibit any possibility of flow between bore 70 and bore 84. Land 66 likewise slides in an O ring seal 100 positioned between bores 72 and 82 to positively seal these bores from each other. In the energised position of the spool 44, the land 66 blocks bore 82 so that fluid does not flow between bores 78 and 80. However, in the de-energised condition, Fig. 3, the land 66 moves so that the bores 78 and 80, and hence the bores 74 and 76, are in communication. Land 68 does not serve any important sealing function but provides a stop for the spring 48 to bear against.

To summarise, therefore, at all times the pair of ports C1 and S3, C2 and S4, P and S1, and T and S2 are each in communication. When the spool 44 is energised, as shown in Fig. 2, the boxes 70 and 72 (ports C1 and C2) do not communicate with each other due to land 64. Also land 66 blocks bore 82, so that bores 78 and 80, and hence bores 74 and 76 (ports P and T), do not communicate with each other. When the spool is de-energised, as shown in Fig. 3, land 64 is removed to place ports C1 and C2 in communication with each other, while land 66 is removed to place ports P and T in communication with each other. These paths of communication are indicated by arrows on Fig. 3. In this condition, the O ring seals 98 and 100 prevent any leakage from the circuit including the actuator ports C1 and C2.

Any leakage between the ports C1 and C2 when these are blocked by land 64 is small and acceptable as a proportional of the overall leakage of the system under normal conditions.

It will be seen that there is a minor difference in the physical construction, though not in the function, of the safety unit 40 as shown in Figs. 2 to 5 from that indicated by the diagram of Fig. 1, in that in Figs. 2 to 5 the bore 74 directly connects ports P and S1 and bore 76 directly connects ports S2 and T without these ports being separated by the spool valve 44. Thus the ports S1 and S2 are in fact branched off from the input lines at the same place as the branches to the solenoid valve 50.

As noted above, the solenoid valve 50 selectively communicates bore 62 with bore 78 or bore 80 in dependence upon whether the solenoid 52 is energised or not. These two conditions are shown in more detail in Figs. 6 and 7. The valve illustrated is a solenoid cartridge valve manufactured by Fluid Controls, Inc., of the United States of America under the model number 7W40—2. The valve is a direct acting

spool style three-way valve and its operation will be apparent from Figs. 6 and 7. briefly, however, when energised as shown in Fig. 6, the valve stem 102 moves to open a port 104 while keeping a port 106 closed, and when de-energised, as shown in Fig. 7, it returns to close port 104 and open port 106. The bores 62, 78 and 80 are shown, and the flow between them is indicated by arrows.

It will thus be seen that when both electric and hydraulic power is present, the solenoid valve 50 is energised to connect bores 62 and 78, and pressure from the pump is applied to move the spool 44 to the position shown in Fig. 2 against the spring 48. If the hydraulic pressure drops, spring 48 will return the spool 44 to the Fig. 3 position. If the electrical supply fails, the pressure will again be removed from the left-hand end of spool 44 by the solenoid valve adopting the position shown in Fig. 7. In either event, the ports C1 and C2 are connected together so that no adverse pressure can prevail across the actuator diaphragm.

#### Claims

1. Hydraulic control apparatus comprising two input ports for connection to a hydraulic pressure differential, two output ports for connection to a controlled unit, a control unit for selectively coupling each of the output ports to a different one of the input ports, and safety means responsive to the absence of a pressure differential at the input ports *and/or* to the failure of an electrical supply so as to cause the output ports to be coupled together.

2. Apparatus according to claim 1, in which the safety means comprises a hydraulically-operated valve coupled to at least one of the input ports to be operated in response to the input pressure differential.

3. Apparatus according to claim 1 or 2, in which the safety means comprises an electrically-operated valve.

4. Apparatus according to both claims 2 and 3, in which the electrically-operated valve is arranged to control the supply of fluid from the input ports to operate the hydraulically-operated valve.

5. Apparatus according to any preceding claim, including an actuator connected across the output terminals for control by the control apparatus, the output ports communicating with a rolling diaphragm in the actuator.

6. Hydraulic control apparatus substantially as herein described with reference to the drawings.